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Evolution patterns of the soil organic matter in some agricultural systems in the Brazilian "Cerrado" region

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Abstract

Several changes in the soil humus characteristics were observed after clearing the Central Brazil virgin forest. When compared with the original "Cerrado" forest, the soils from the agricultural systems showed increased values for cation exchange capacity, total organic matter and non-extractable humin. The humic acid fraction underwent some changes suggesting increased oxidation and decreased aliphatic content. The soil organic N tends to accumulate in the insoluble humus fractions.

The above changes were much less intense when the virgin forest was transformed into pastures. Under these conditions, the most significant changes were the reduction of readily biodegradable soil organic matter fractions.

In view of the intensity of the lixiviation processes in the area studied, the above changes may be connected with the reduction in aggregate stability observed in the cleared sites.

In general, the characteristics of the humus formations in the "Cerrado" region suggested high resistance to external factors, which is in part attributed to the active insolubilization of humic colloids by the Al and Fe oxides. In the absence of erosive processes in the cleared sites, additional humus stability may conform both to selective biodegradation and/or lixiviation of the humic colloids, or to the effects of the fire used in soil management.

Keywords: Soil, humus, Brazil, Cerrado region, clearing, cultivation, humic acid, fulvic acid.

Évolution de la matière organique du sol dans quelques agrosystèmes de la région des Cerrados (Brésil Central).

Résumé

Après l'élimination de la forêt vierge dans la région centrale du Brésil, on a constaté des changements dans les caractéristiques de l'humus. Les sols des agrosystèmes, comparés à ceux de la forêt de la région des Cerrados, montrent des valeurs plus élevées de capacité d'échange cationique et de teneur en matière organique totale et en humine d'insolubilization non-extractible. La fraction humique montre aussi des transformations après déforestation : elle présente un degré plus élevé d'oxydation et une diminution de la teneur en composés aliphatiques. En même temps, l'azote organique du sol est incorporé aux fractions insolubles de l'humus.

On a observé des changements beaucoup moins intenses quand la forêt vierge a été transformée en pâturage. Dans ce cas, les transformations les plus importantes correspondent à la diminution de la matière organique du sol, après une dégradation sélective des formes de C et N moins étroitement incorporées à la matrice minérale du sol. Si on fait attention à l'importance du lessivage dans la région étudiée, les transformations produites peuvent être reliées à la diminution de la stabilité des agrégats du sol dans les zones déforestées.

Les caractéristiques générales de l'humus des sols de la région des Cerrados suggèrent une assez grande résistance aux agents externes, qui peut être partiellement expliquée par l'insolubilisation des colloïdes humiques par des oxydes de Fe et Al. Si le sol n'est pas affecté par l'érosion après l'élimination de la forêt, l'humus peut être soumis à des processus de stabilisation comme conséquence de la biodégradation et/ou le lessivage sélectif de colloïdes humiques ou de l'action du feu utilisé pour la mise en culture.

Mots-clés : Sol, humus, Brésil, région des Cerrados, déforestation, culture, acides humiques, acides fulviques.

INTRODUCTION

The "Cerrado" is the most characteristic phytosociological formation in Central Brazil. This region covers 21 % of the total national area, and is receiving increased attention because of the agricultural potential of its soils. In spite of the favourable climatic conditions and soil hydrophysical properties in this area, the content of humus is low as are the available nutrients and the pH values. These chemical conditions are partly due to the presence of exchangeable aluminum, often at toxic levels for agricultural crops (Nascimento *et al.*, 1983). The soil organic matter plays an important role due to the dominant kaolinites and iron and aluminum oxides only make a small contribution to the soil exchange properties (Nascimento, 1981; Nascimento *et al.*, 1988).

As a consequence of the "Cerrado" colonization, extense areas were burned and converted into pastures, or into different types of cultures (Fernandes *et al.*, 1985). Such changes in the original status of the virgin ecosystems should be reflected in the characteristics and distribution of the soil humus.

Due to the importance of the physico-chemical fertility of the soil organic matter in the "Cerrado" region, this study focuses on the evolution of humus after clearing the virgin forest.

MATERIAL AND METHODS

Sites studied

Sampling was carried out at the UNESP Experimental Farm of Agricultural Engineering (20° 22' S, 51° 22' W; altitude 335 m, precipitation 1300 mm yr^{-1} and mean temperature 23.7 °C). The landscape of the "Cerrado" region is characterized by a vegetation of variable density, consisting of medium-sized (8-15 m) trees (mainly *Qualea grandiflora, Caryocar brasiliense, Dalbergia violacea* and *Pterodon pubescens*) and brushwood (*Casearia sylvestris, Davilla elliptica* and *Salacia crassifolia*). The herbaceous layer includes *Gramineae* in addition to several *Cyperaceae* (Ribeiro *et al.*, 1983).

Nine soil samples were taken at different sites representative for the virgin area and the most frequent agricultural systems. The three situations studied correspond to the original "Cerrado" formation (1), the cleared sites used for rotative cultures of maize, rice, soybean or beans (2), and the cleared sites used as pastures of *Brachiaria decumbens* and other Gramineae (3). The soils studied were sandy Haplustox and were reclaimed in the last 12 years.

Analysis of the soil organic fractions

The litter material was removed and the soil samples were taken from the upper 10 cm of the soil profiles, air-dried and sieved to 2 mm.

After the previous separation of the plant residues by flotation with 0.1 *M* H_3PO_4, the colloidal humic substances were extracted by repeated treatments with 0.1 *M* $Na_4P_2O_7$ and 0.1 *M* NaOH (Dabin, 1971). The extraction residue (humin) was subjected to successive treatments with $Na_2S_2O_4$ 60 m*M* and HCl-HF (1 : 1) 1 *M* (Merlet, 1971) then extracted several times with 0.5 *M* NaOH to recover the humic fraction in stable association with the clay and the iron and aluminium oxides (extractable insolubilized humin; Duchaufour and Jacquin, 1975). Both the humic extracts separated after or before the demineralizing treatments were precipitated with HCl to separate the insoluble humic acid fraction from the soluble fulvic acids; the quantitative determinations were carried out in desiccated aliquots. The above extracts in addition to the H_3PO_4 surnatant containing some coloured organic matter were aggregated for further qualitative studies of the humic substances.

Purification and analyses of the humic fractions

The humic acid was precipitated from the total extract with HCl and purified by overnight treatment with the HCl-HF 1 *M* mixture, followed by redisolution in 0.5 *M* NaOH, centrifugation at 43500 *g*, reprecipitation and dialysis.

For its purification, the acid-soluble fulvic fraction was concentrated in a column with insoluble polyvinylpyrrolidone (PVP) (Divergan® R, BASF). Since the adsorption of the fulvic extracts on this resin is incomplete, it is considered that the coloured materials retained at acid pH consist of the fulvic molecules of a predominantly aromatic nature, whereas the colourless eluent include carbohydrate-like polymers (Lowe, 1975). The former fraction was eluted with 0.1 *M* NaOH and obtained in the H^+ form in a column with Amberlite® IR-120 (H).

The concentrations of C, H, N and S of the humus fractions were determined with a Heraeus CHN-O Rapid microanalyzer. Afterwards, the percentages were expressed on an ashfree basis and the oxygen was calculated by the difference.

Additional parameters were determined in the case of the humic acids. The spectroscopic measurements in the visible range, as well as the determination of the E_{465}/E_{665} ratios (Chen *et al.*, 1970) were carried out with 0.02 *N* $NaHCO_3$ solutions of 136 ppm C (Kononova, 1961). The infrared (IR) spectra were obtained in a Perkin-Elmer 680B spectrophotometer (KBr pellets with 2.00 mg of sample). Comparative values were obtained by dividing the peak intensities by that of the aromatic vibration at 1510 cm^{-1} (Dupuis and Jambu, 1969).

An estimation of the apparent molecular size distribution, and ionic charge of the humic acid macromolecules was carried out from their electrophoretic fractionation patterns, which were obtained on Whatman # 1 paper using phosphate buffer (pH = 7)

at 150 V for one hour. The electrophoregrams were integrated at 525 nm with a densitometer Gelman DCD 16 in the transmission mode, and the densitometric curves were divided into three regions of different ionic mobility.

Other analyses

The cation exchange properties of the soils were determined at pH = 8 (Mehlich, 1948) and for the aggregate stability the wet sieving afer benzene pretreatment was used (Henin *et al.*, 1972). The multivariate data treatment was performed by the STATITCF programs (ITCF, 1988).

RESULTS

The general characteristics of the soil organic matter and of the major humus fractions are summarized in *table* 1.

In general, the characteristics of the virgin "Cerrado" soils are very similar to those in the derived agricultural systems. *Table* 1 shows the low values of soil C (*ca* 1 %), the C/N ratios of about 10, and the negligible amounts of non-decomposed plant residues (free organic matter). Such characteristics correspond to intense mineralization processes of the soil organic matter. There was high proportions of humic colloids insolubilized in a mineral matrix with the dominance of Al and Fe oxides (extractable humin *ca* 27 % of the total organic carbon). The humic acid/fulvic acid ratios of these soils are about 0.7.

Mainly at the cultivated sites, the most significant differences concerned the relative increase in the amounts of the organic matter forms tightly bonded to the mineral fraction (non-extractable humin). In the case of the fulvic acids, the predominantly aromatic fraction (PVP-retained) increased to a significant extent, which agreed with their atomic H/C ratios (*table* 1).

Concerning the distribution of the soil N within the different organic fractions, it was observed that *ca* 20 % of the total N was in the humic acid-type colloids, while between 19-37 % remain in the non-extractable humic matter retained by the mineral fraction. The difference between the fractions accounted for and the total N was considered largely to consist of the extractable and labile N compounds present in the fulvic fraction not adsorbed in the PVP. The tendency observed in the agricultural systems was the relative increase of the most stable and insoluble N forms.

Finally, some changes in the humic acid characteristics (E_{465}/E_{665} ratio, and relative intensity of the IR 1720 and 1240 cm^{-1} bands) agreed with the oxidative processes suggested by the atomic O/C ratios.

The evolution of the humus characteristics from the virgin "Cerrado" soils to the agricultural systems are illustrated in *figure* 1, where the scores calculated for both the samples and the variables are simultaneously plotted in the space defined by the two first axes obtained from factorial analysis of correspondences (total variance explained = 83 %).

DISCUSSION

The differences between the three situations studied in terms of the soil organic matter characteristics are reflected by *figure* 1: axis II includes the information about the evolution from the virgin to the cleared areas, whereas axis I leads to further differentiation between the agricultural soils and the pastured sites. The high homogeneity of the soil characteristics in the region studied is reflected on the plot by the central situation of most of the variables, although those showing values characteristic of the different situations appeared in the neighborhood of the corresponding sample clusters.

The arrangement for the variables suggested that the humus evolution paths from the virgin sites to the two types of agricultural systems has several common features which may be interpreted as the effects of some lixiviation processes on soil humus formations that have suffered slight oxidative diagenetic processes, as reflected by the E_{465}/E_{665}, IR 1720/1510 and atomic O/C ratios. The former parameter is considered to be in relation to low molecular complexity and high carboxyl content (Chen *et al.*, 1977) whereas the latter two suggest enhanced number of acidic functional groups in the humic molecules, that also showed decrease of the aliphatic content (IR 2920/1510 cm^{-1} ratio).

Such processes seem to be dominant in the case of cultivated ecosystems although they present increased values for soil C, which may in part explain their increased cation exchange and water-holding capacities. On the other hand, the pasture sites differed mainly in respect of the increased values of the humic acids for ionic mobility, and the humic acid/fulvic acid ratio. This suggests an active dynamism of the low MW humus fractions, whereas the levels for the total extractable humus, atomic H/C ratio and IR 2920/1510 cm^{-1} ratio point to common humification patterns in the virgin forest.

The accumulation of stable C and N forms in the cleared sites, together with the changes in the aliphatic and carboxyl content of the humic acids, may either be considered the effect of the microbial reworking of the soil organic matter, or the result of moderate burning during forest fires (Almendros *et al.*, 1984, 1991). In fact, fire is the traditional agent used for the management of the soils in the "Cerrado" region (Coutinho, 1990).

Under the climatic conditions in the area studied, the role of iron and aluminium oxides in insolubilizing the soil organic colloids (Toutain, 1981) and the

Table 1. – Analytical characteristics of soil humus in virgin forest and agricultural systems in the Brazilian "Cerrado" region.

Characteristic	Virgin forest value	Agricultural systems			
		Agricultural soils		Pastured sites	
		value	% increase	value	% increase
Soil properties,					
pH (H_2O)	4.9	5.1		5.2	
Water holding capacity, g 100 g^{-1}	51.3	58.6		34.6	(−32.6)
Stable aggregates, g 100 g^{-1}	52.4	30.9	(−41.0)	29.1	(−44.5)
Available K_2O, mg 100 g^{-1}	5.2	21.7	(+317.3)	2.7	
Available Ca, mg 100 g^{-1}	8.7	28.3	(+225.3)	17.2	
Available Mg, mg 100 g^{-1}	3.9	11.0		8.33	
Available P, mg 100 g^{-1}	1.2	1.0		1.0	
Cation exchange capacity (pH=8), $cmol_c$ kg^{-1}	8.0	15.7	(+96.3)	8.4	
Total soil carbon, g 100 g^{-1}	1.08	1.61	(+49.1)	0.70	(−35.2)
Total soil N, g 100 g^{-1}	0.11	0.14	(+27.3)	0.06	(−45.5)
C/N ratio	9.8	10.5		12.2	
Humus fractions,					
Free organic matter, g C (100 g soil)$^{-1}$	0.03	0.05		0.02	
Humic acids (HA), g C (100 g soil)$^{-1}$	0.19	0.24		0.15	
Fulvic acids (FA), g C (100 g soil)$^{-1}$	0.32	0.37		0.17	(−46.9)
FA (adsorbed on PVP) / FA (eluent)	0.32	0.60	(+87.5)	0.80	(+150.0)
Total humic extract (HA+FA), g C (100 g soil)$^{-1}$	0.52	0.61	(+17.3)	0.32	(−38.5)
HA/FA ratio	0.59	0.65		0.86	
Extractable humin (HA-like), g C (100 g soil)$^{-1}$	0.08	0.10		0.08	
Extractable humin (FA-like), g C (100 g soil)$^{-1}$	0.22	0.37	(+68.2)	0.10	
Total extractable humin, g C (100 g soil)$^{-1}$	0.30	0.47		0.18	
Non-extractable humin, g C (100 g soil)$^{-1}$	0.22	0.48	(+118.2)	0.17	
Free organic matter, g C (100 g soil C)$^{-1}$	3.0	3.4		4.3	
Humic acids (HA), g C (100 g soil C)$^{-1}$	17.6	14.8		21.3	
Fulvic acids (FA), g C (100 g soil C)$^{-1}$	31.1	23.4		25.2	
Total humic extract (HA+FA), g C (100 g soil C)$^{-1}$	48.7	38.2	(−21.6)	46.5	
Extractable humin (HA-like), g C (100 g soil C)$^{-1}$	7.5	5.8		10.9	
Extractable humin (FA-like), g C (100 g soil C)$^{-1}$	20.0	22.7		13.8	
Total extractable humin, g C (100 g soil C)$^{-1}$	27.5	28.5	(+48.5)	24.7	
Non-extractable humin, g C (100 g soil C)$^{-1}$	20.0	29.7		24.2	
Elementary composition of humic substances,					
Humic acid C, g (100 g)$^{-1}$	54.7	52.6		54.1	
Humic acid H, g (100 g)$^{-1}$	4.8	4.5	(−7.1)	4.9	
Humic acid O, g (100 g)$^{-1}$	35.7	38.3	(+7.3)	36.5	
Humic acid N, g (100 g)$^{-1}$	3.9	3.9		4.0	
Humic acid S, g (100 g)$^{-1}$	0.4	0.6	(+50.0)	0.5	
C/N ratio (Humic acid)	14.0	13.5		13.5	
Atomic H/C ratio (Humic acid)	1.06	1.01		1.05	
Atomic O/C ratio (Humic acid)	0.50	0.55	(+10.0)	0.48	
Fulvic acid C, g (100 g)$^{-1}$	44.6	49.1	(+10.1)	48.4	
Fulvic acid H, g (100 g)$^{-1}$	4.9	4.7		5.0	
Fulvic acid O+S, g (100 g)$^{-1}$	47.8	43.5		43.6	
Fulvic acid N, g (100 g)$^{-1}$	2.7	2.7		3.0	
C/N ratio (Fulvic acid)	16.8	18.0		16.2	
Atomic H/C ratio (Fulvic acid)	1.33	1.14	(−14.2)	1.25	
Atomic O/C ratio (Fulvic acid)	0.81	0.67		0.68	
Nitrogen speciation,					
% N in humic acids, g N (100 g soil N)$^{-1}$	17.3	17.2		27.7	
% N in fulvic acids, (PVP-fraction), g N (100 g soil)$^{-1}$	7.2	11.0	(+52.8)	12.0	(+66.7)
% N in non-extractable, g N (100 g soil N)$^{-1}$	21.6	36.2	(+67.6)	28.3	(+31.2)
Difference to 100 %, g N (100 g soil N)$^{-1}$	53.9	35.6		31.9	(−16.5)
Humic acid N / fulvic acid N	0.29	0.37	(+27.6)	0.63	(+117.2)
Characteristics of rhe humic acids,					
Extinction at 465 nm (E_{465}) [0.196 mg C ml^{-1}], AU	1.54	1.68		1.48	
E_{465}/E_{665} ratio	4.70	5.05	(+7.4)	4.65	
Low ionic mobility fraction (%)	40	42		26	
Medium ionic mobility fraction (%)	18	25		22	
High ionic mobility fraction (%)	42	33	(−21.4)	52	(+23.8)
3 400/1 510 cm^{-1} ratio (IR spectra)	1.67	1.64		1.54	
2 920/1 510 cm^{-1} ratio (IR spectra)	0.31	0.17	(−45.2)	0.28	(−9.7)
1 720/1 510 cm^{-1} ratio (IR spectra)	1.32	1.43	(+8.3)	1.31	
1 240/1 510 cm^{-1} ratio (IR spectra)	1.06	1.16	(+9.4)	1.10	

Average values for three soil samples taken at different sites. In the cases in which the mean values for each of the agricultural systems were significantly different ($P < 0.05$ %) from that in the soils at the virgin "Cerrado" sites, the percentage increase in comparison with to the latter are given in brackets.

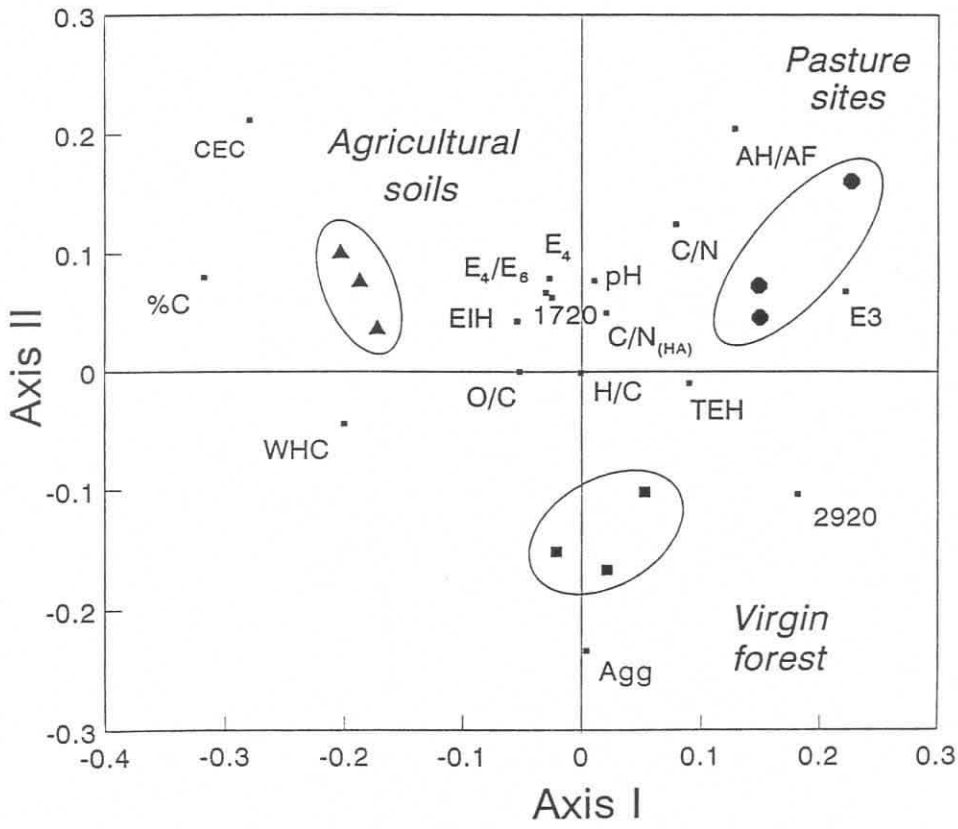

Figure 1. – Sample arrangement obtained after a factorial analysis of correspondences from soil characteristics determined in the Brazilian "Cerrado" region. The scores for the variables processed are also shown: (left to right, top to bottom: **CEC:** cation exchange capacity; **HA/FA:** humic acid/fulvic acid ratio, **C/N:** soil C/N ratio, **% C:** % of soil C, $\mathbf{E_4}$**:** extinction at 465 nm the humic acids; **pH:** soil pH; $\mathbf{E_4/E_6}$**:** extinction ratio of the humic acids; **1720:** IR 1720/1510 cm^{-1} ratio of humic acids; **E3:** percentage of the humic fraction with greatest ionic mobility; **EIH:** % C as total extractable insolubilized humin; $\mathbf{C/N_{(HA)}}$**:** C/N ratio of the humic acids; **O/C:** atomic O/C ratio of the humic acids; **H/C:** atomic H/C ratio of the humic acids; **TEH:** % C as total extractable humus (humic acid + fulvic acid); **WHC:** soil water holding capacity; **2920:** IR 2920/1510 cm^{-1} ratio; **Agg:** soil stable aggregates).

effect of fire on the preferential accumulation of insoluble humus fractions (Almendros *et al.*, 1990), seem to be factors responsible for the high stability of the soil organic matter. For these reason, the results obtained suggest that – with the exception of the changes in some readily biodegradable humus fractions in probable connection to soil physical parameters – the contrasted agricultural practices are not leading to humification processes divergent to those in the original forest.

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